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Real data analysis and efficiency of the TEA Mantova Casale (Italy) variable-speed pumping station

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Abstract

Variable speed pumps (VSPs) are widely used in water distribution systems (WDSs). They can increase the efficiency of the system and reduce the energy consumptions, when the functioning conditions move away from those used for the design. Affinity laws allow to model the characteristic curve of VSPs, in terms of dimensionless flow, head and power. Efficiency of the VSPs can also be predicted, although the effects of the variation in the rotation speed can be questioned. In this paper, the experimental data acquired by TeaAcque at the Mantova Casale pumping station are interpreted by means of the dimensionless equations derived by the affinity laws. The measured "wire to water" efficiency of the system is compared to the theoretical one.

Keywords: variable speed pump; efficiency; water distribution system; affinity law

1. Introduction

Variable speed pumps (VSPs), are widely used in water distribution systems because they can adjust the pump curve more efficiently than fixed speed pumps so as to meet the network requirements. When the system functioning conditions require a change in pump flow and head, the pump speed and characteristic curve is varied consequently. In these cases, in order to interpret the pumps behaviour, taking into account the system request changes and the pump speed variations, a model is needed. An effective way is to use affinity laws. They allow to model the VSPs curve by means of three dimensionless quantities, depending on the pump speed. Since these relationships cannot take into account the factors that do not scale with velocity, Simpson and Marchi evaluated the approximation of affinity laws for different pump sizes. They also tested a formula developed by Sârbu and Borza (1998), who proposed a relationship between the pump speed variation and the corresponding efficiency variation. This work comes from a collaboration between TeaAcque and the University of Perugia. TeaAcque is the company that manages the water

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Fig. 1. A photograph taken inside the Casale pumping station.

supply in Mantova, a town in the north of Italy. TeaAcque provided a set of measures for one of its pumping stations (Casale). The purpose of this collaboration is to obtain an analysis of these data in order to improve the efficiency of the pumps. The affinity laws have been used to model the data and fit the pump curves. In particular, a quadratic polynomial has been used to approximate the data in terms of dimensionless head and dimensionless flow, according to Ulanicki et al. (2008). A cubic polynomial has been used for the fitting of the stream flow power and efficiency data.

2. Data collected at Casale pumping station

The Casale pumping station is equipped with four Etanorm 65-200 KSB pumps (Fig.1), feeded by a tank. The data provided by TeaAcque refer to a single VSP working. At the downstream of the pump there is a pressure transducer, placed at a height of $z_m = 2.20$ m above the ground (Fig.2). Tea provided a set of measures, for the duration of a week, of:

- tank level, h_L (m)
- pressure at the downstream of the pump, p_{val} (bar)
- pump flow, Q (m^3/s)
- pump speed, N (rpm)
- input power, P_{att} (kW).

The input power is acquired at 1/900 Hz, while the other data are acquired at 1/60 Hz. To evaluate the pump head, H, the following expression has been used:

$$H = \frac{p_{val}}{\gamma} + z_m - h_L \tag{1}$$

where local head losses are negligible, with γ being the specific weight of water (N/m^3). The time-histories of the raw acquired data, H and Q, in Figs.3a and 3b show a clear one week periodic component. The same data of Figs.3 do not lie on a single curve in the Q-H domain (Fig.4), but on several curves, corresponding to the different pump speeds.

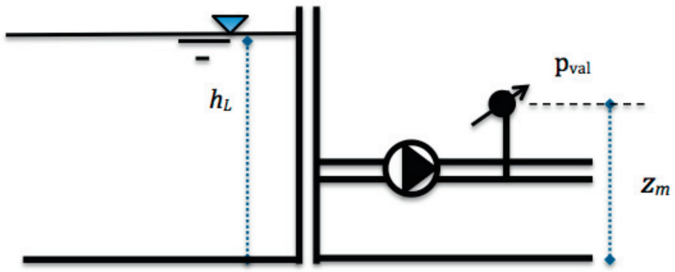

Fig. 2. The scheme of the system.

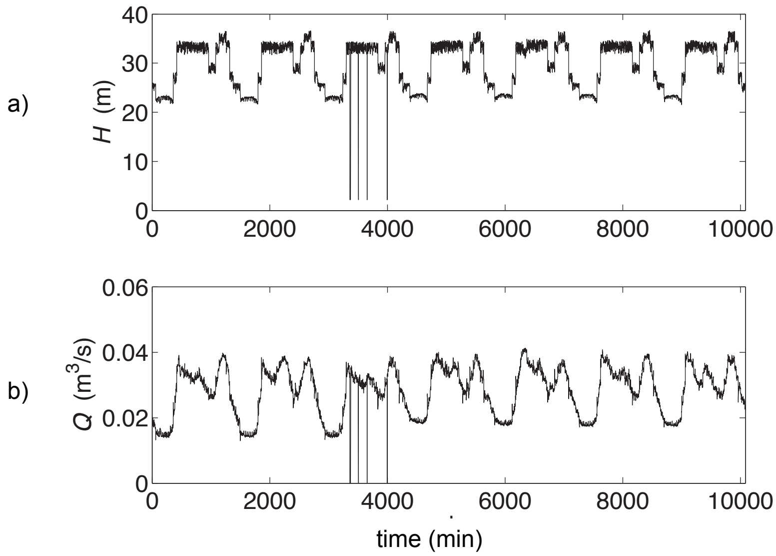

Fig. 3. The raw data acquired of (a) pump head, H (m) and (b) pump flow, Q (m^3/s).

3. Data analysis

For VSPs, the dimensionless quantities defined by the affinity laws

$$C_q = \frac{Q}{ND^3} \tag{2}$$

$$C_h = \frac{gH}{N^2D^2} \tag{3}$$

$$C_p = \frac{P}{\rho N^3 D^5} \tag{4}$$

can be used to describe the relationship between the quantities involved in pump performance, such as flow, total head and power, and the pump speed (Simpson and Marchi). In Eqs. (2) - (4), ρ is the water density (kg/m^3), g is the acceleration of gravity (m/s^2) and D is the impeller diameter (m). These three expressions can be used to model the pump curves.

3.1. Pump hydraulic characteristics

Plotting dimensionless pump head, C_h, in terms of dimensionless pump flow, C_q, a characteristic curve scaled with respect to the pump speed is obtained and the experimental data are arranged on a single curve (Fig.5). The design characteristic curve plotted on the same figure, does not allow to interpret the experimental data. Thus, the quadratic polynomial proposed by Ulanicki et al. (2008) is used to fit the experimental data:

$$C_h = -2.8581 * 10^4 C_q^2 + 0.2274 C_q + 5.7663 * 10^{-6} \tag{5}$$

It can also be seen that there is a good agreement between the fitting and the experimental data distribution (R^2=0.9967).

3.2. Power

Evaluating the stream flow power, P_{th}, by the following expression:

$$P_{th} = \gamma Q H \tag{6}$$

and scaling this quantity with respect to the pump speed by means of Eq. (4), the dimensionless input power, $C_{p,att}$ and the dimensionless stream flow power, $C_{p,th}$ can be compared (Fig.6). The lack of data does not allow to define a clear link between these two quantities, but, focusing on the considered $C_{p,th}$ range, it can at least be noted that the $C_{p,att}$ values are about twice the $C_{p,th}$ ones (Fig.7). However, if $C_{p,th}$ is plotted against C_q, data points are arranged in a shape that reminds a third degree curve (Fig.8). Indeed, experimental data can be fitted by means of a cubic polynomial:

$$C_{p,th} = -6.492 * 10^5 C_q^3 + 13.17 C_q^2 + -4.883 * 10^{-5} C_q + 3.294 * 10^{-10} \tag{7}$$

Also in this case, the agreement between data and fitting is quite good (R^2=0.9874).

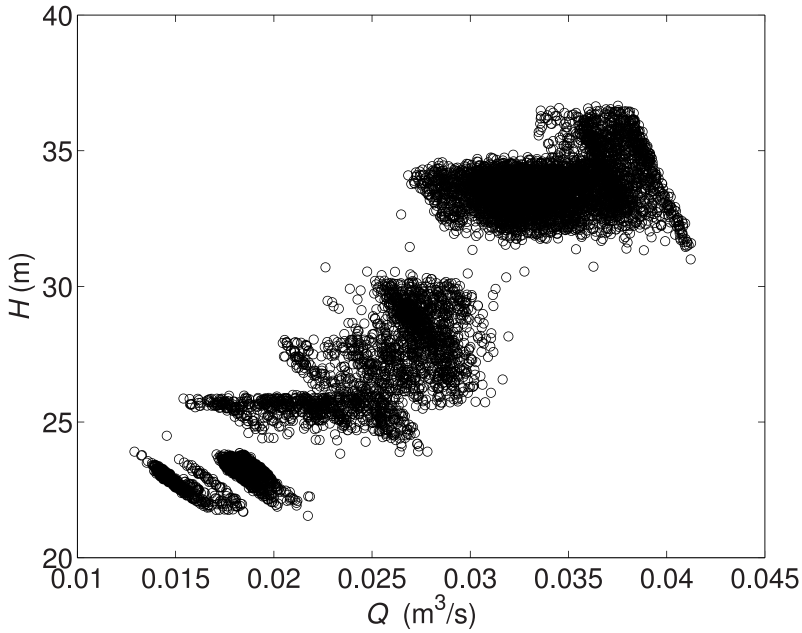

Fig. 4. Plotting of data acquired of pump head, H (m) against pump flow, Q (m^3/s).

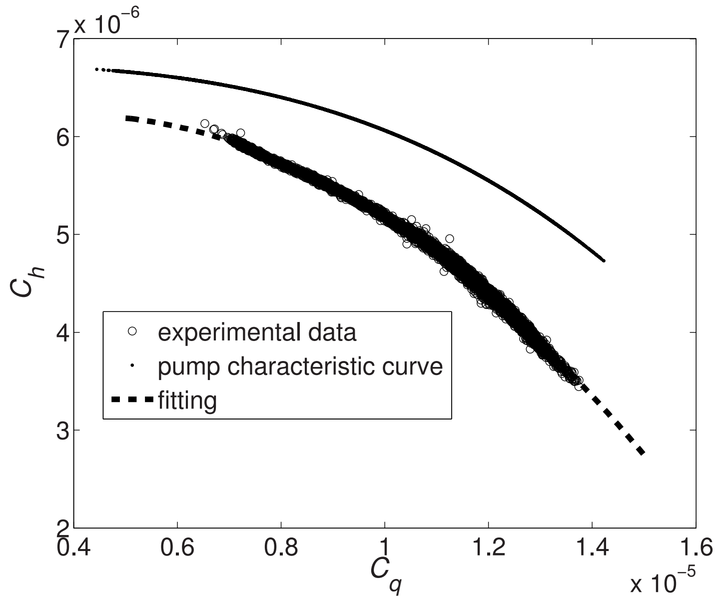

Fig. 5. Experimental data, design curve and the fitting by Eq.(5) plotted in the C_q-C_h plane.

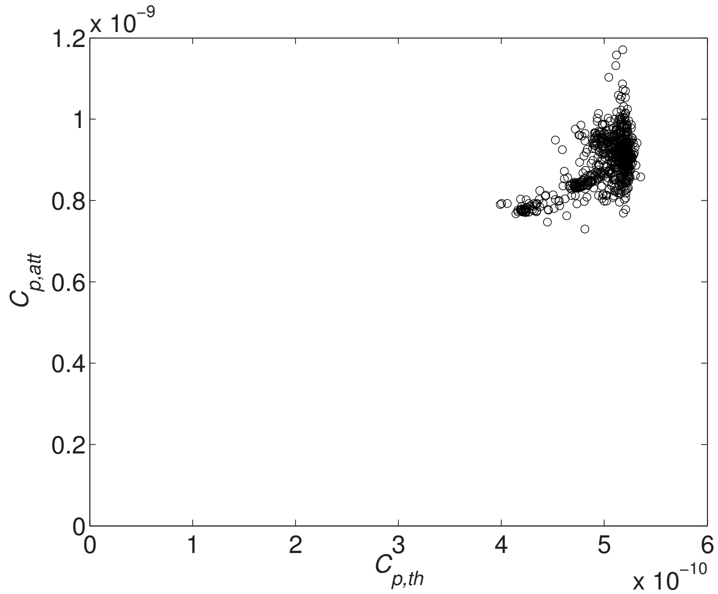

Fig. 6. Dimensionless input power, $C_{p,att}$, vs. dimensionless stream flow power, $C_{p,th}$.

3.3. Efficiency

The efficiency, η, is a dimensionless parameter that allows to evaluate the goodness of the system performance. It can be calculated as the ratio between the stream flow and the input power:

$$\eta = \frac{P_{th}}{P_{att}} \tag{8}$$

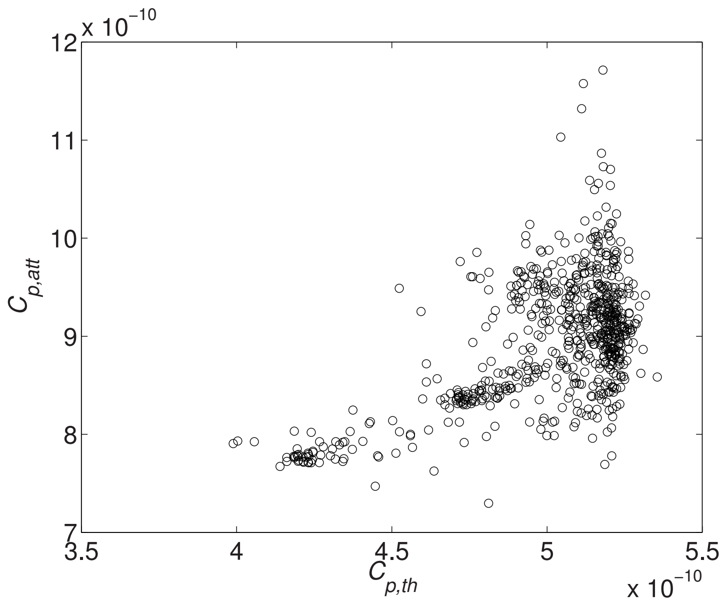

Fig. 7. Dimensionless input power, $C_{p,att}$, vs. dimensionless stream flow power, $C_{p,th}$ zoomed in.

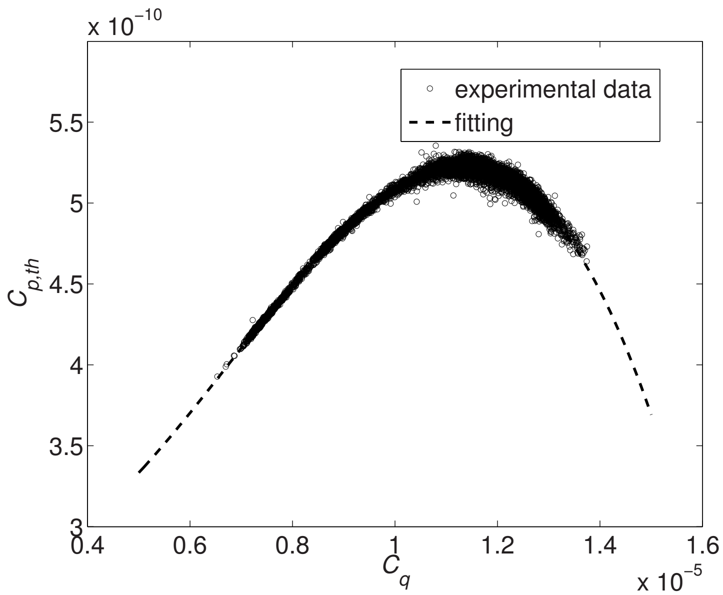

Fig. 8. Dimensionless stream flow power, $C_{p,th}$, vs. dimensionless flow, C_q: experimental data and fitting.

Values obtained by means of Eq.(8) are reported in the η-C_q plane in Fig.9. Firstly it can be noted that the η values are rarely above 0.6. It must be said that such an efficiency is a "wire to water" efficiency, which takes into account many factors and so it is not surprising to meet such values. Secondly, although the data spreading is higher than in the previous graphs, a fitting has been made by a cubic polynomial:

$$\eta = -1.185 * 10^5 C_q{}^3 + -5.66 * 10^9 C_q{}^2 + 1.144 * 10^5 C_q \tag{9}$$

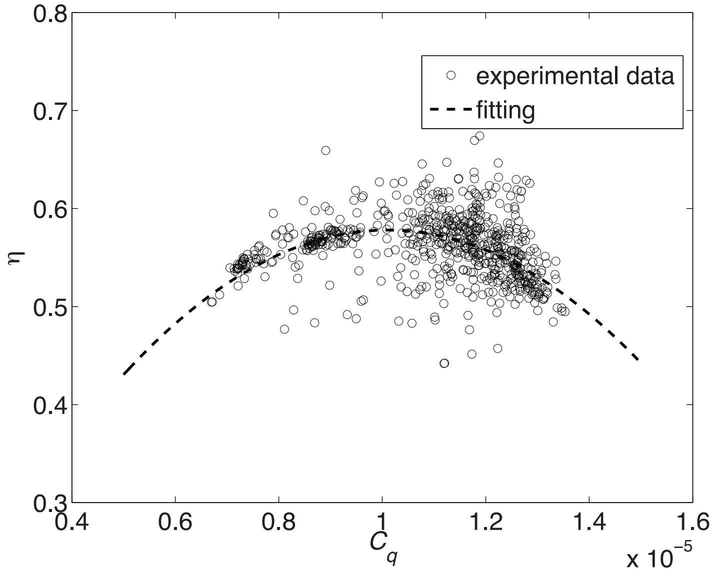

Fig. 9. Efficiency values in terms of dimensionless flow, C_q: experimental data and fitting.

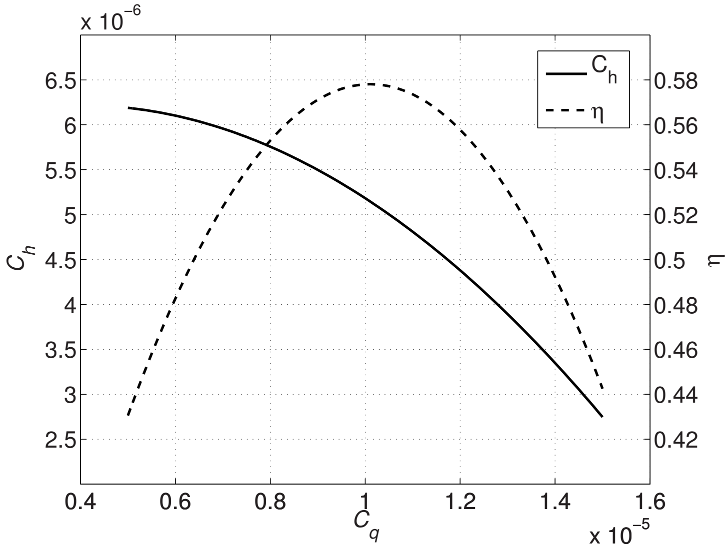

Fig. 10. Fittings of data of Fig.5 and 9 plotted on the same plane.

with R^2=0.1596. For the sake of clarity, both fittings of C_h (Fig.5) and η (Fig.9) in terms of C_q are plotted on Fig.10.

4. Conclusions

When the behaviour of variable-speed pumping station has to be analyzed, measurements of pump speed and input power, more than pressure and flow data, can be useful for management purposes. Pump speed data allow to scale hydraulic pump characteristics, i.e. pump head and flow, and to model the pump behaviour, in terms of pump characteristic curves, by means of affinity laws. In this paper a set of measures from the Casale pumping station is considered, for the duration of a week. The measures are analyzed using the three dimensionless quantities introduced by affinity laws. The data in the dimensionless plane C_q-C_h can be fitted with a quadratic polynomial, with a good agreement and there is no correspondence with the design characteristic curve. Evaluating the dimensionless stream flow power, it is possible to fit its distribution in terms of dimensionless flow by means of a cubic polynomial, with a quite good agreement. The stream flow power can be compared with the measured input power: the ratio between these two quantities allows to evaluate the "wire to water" efficiency, η, of the system. The η experimental data show a high spreading and their fitting is characterized by a worse agreement if compared with previous fittings. This is a first attempt in the analysis of Casale pumping station data. Combining this analysis with a larger set of data will allow to improve the pumping station functioning conditions and so to reduce the costs of the system management.

Acknowledgements

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